







New records of polymorphism in Asian libellulid dragonflies (Insecta: Odonata)

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Polymorphism has rarely been reported from dragonflies of the Libellulidae (Odonata: Anisoptera) family. Here, we report female-limited polymorphism in females of five species of the Libellulidae and a gynandromorph male of *Brachythemis contaminata* from South Asia. We describe the morphological variation between andromorph and heteromorph females, and collate records of andromorph females from various sources. Yearly number of andromorph females of *Crocothemis servilia*, *Urothemis signata* and *Neurothemis tullia* was calculated using records from published literature and unpublished sources, and social media.

Keywords: polymorphism; andromorph; gynandromorph; *Crocothemis*; *Urothemis*; *Neurothemis*; *servilia*; *signata*; India; citizen science; dragonfly

Introduction

Polymorphism is the presence of two or more different phenotypes with a genetic basis, within a species occupying the same habitat, at the same time, and within a panmictic population. Odonates are an interesting group of insects to study the evolution and maintenance of multiple color forms or polymorphism because more than 100 species are known to exhibit color polymorphism (Fincke, Jödicke, Paulson, & Schultz, 2005; reviewed in Van Gossum, Sherratt, & Cordero-Rivera, 2009). They are a relatively well-studied, conspicuous and widespread group of insects and convenient to observe *in situ*. Odonates have well-developed color vision, as they rely heavily on their vision for survival, to capture prey and elude predators (Corbet, 1999). Color vision is also important for mate-recognition and other behaviors such as male–male conflicts (Corbet, 1999; Huang, 2014). Hence, color polymorphism has functional consequences in this group of insects.

Color polymorphism is widespread in odonates, but it is more common in damselflies (Zygoptera), than in dragonflies (Anisoptera) (Fincke et al., 2005). It has been shown in several

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species of damselflies that the development of the different forms is genetically controlled, and is consistent with a single-locus two-allele autosomal genetic polymorphism (Sánchez-Guillén, Van Gossum, & Cordero-Rivera, 2005; Tsubaki, 2003). In female-limited color polymorphism only females exhibit color variants. In odonates, the most common scenario is the occurrence of one male-like form (andromorph) and one or more female-like forms (heteromorphs). We use the term “andromorph” here to denote females with male-like coloration and “heteromorph” for females with coloration different than that of adult males (Johnson, 1975; see Fincke et al., 2005). Andromorph has been used interchangeably in odonate literature with androform (Asahina, 1981), androchrome (Bedjanič, Conniff, van der Poorten, & Salamun, 2014; van der Poorten, 2007), androchromotype (Hilton, 1989; Seehausen, 2017), and isochrome (Lahiri, 1979; Laidlaw, 1926).

Andromorphic individuals may differ from typical non-andromorphic individuals not just in color, but also in behavior (Van Gossum et al., 2001). Though vision is assumed to be the primary means by which a male identifies a female, Frati et al. (2015) showed that in the lab, males of *Ishcnura elegans* (Vander Linden, 1820), a damselfly with polymorphic females, were able to perceive odors with their antennae and preferred odors from females to odors from males. Rebora et al. (2018), however, showed that odor cues are insufficient for sex or morph recognition under field conditions in this species.

Baseline data about color polymorphism in the Libellulidae (Anisoptera) is scarce, especially from regions like Asia where odonates are relatively under-studied. Previous to this study, andromorph females had been reported from only five species in the Libellulidae: *Camacinia gigantea* (Brauer, 1867), *Crocothemis servilia*, *Neurothemis fluctuans* (Fabricius, 1793), *Neurothemis fulvia* (Drury, 1773) and *Neurothemis intermedia* (Rambur, 1842). In this note, we report new records of andromorph females in the following five Libellulid species: *Crocothemis servilia* (Drury, 1773), *Diplacodes trivialis* (Rambur, 1842), *Neurothemis tullia* (Drury, 1773), *Orthetrum pruinosum* (Burmeister, 1839), and *Urothemis signata* (Rambur, 1842). All records are based on photographs, except for a single andromorph female of *Crocothemis servilia* that was collected by SJ at Dimapur, Nagaland, India. Except for *Neurothemis tullia*, andromorph females had not been described in detail for the other four species identified in this study.

Gynandromorphs are individuals that have a mixture of morphological traits from both males and females. Gynandromorphs may occur due to a developmental error in early zygote cell division (Siva-Jothy, 1987). Bilateral gynandromorphs are individuals with male and female coloration on two lateral halves of the body. Gynandromorphs have been reported in the Odonata (Corbet, 1999; Yokota and Asahina, 1953), but bilateral gynandromorphism has rarely been reported and only around 30 specimens are known (Gloyd, 1971; Tennessen, 2008; Torralba-Burrial & Ocharan, 2009). A bilateral gynandromorph female (based on caudal appendages and absence of secondary genitalia) of *Neurothemis tullia* with one half colored like the male and the other half like the usual adult female was recently reported from India (Shome, Mokhesur, & Alam, 2019). In this note, we report the first observation of bilateral gynandromorphism from India and the first for *Brachythemis contaminata* (Fabricius, 1793), a male.

Material and methods

Three sources of data were used: (1) unpublished observations; (2) records posted on citizen-science and social media websites (e.g. indianodonata.org, flickr.com, and various Facebook groups such as DragonflySouthAsia); and (3) existing literature (Table 1).

- (1) Unpublished observations. All records are based on photographs taken using digital cameras by individual authors in different localities, except for one specimen that was collected. One

andromorph female of *C. servilia* (NCBS-AV624) was collected from Diphupar “B”, Dimapur, Dimapur District, Nagaland, India (GPS Co-ordinates: 25.85567 N, 93.75802 E; leg. Shantanu Joshi), on 9 October 2016 with an insect net and was preserved in 99% ethanol; it is currently deposited at Research Collections, National Center for Biological Sciences, Bangalore, India. This female was dissected to check for eggs that were photographed (Figure 2c, d) using a stereomicroscope (Leica Microsystems, Germany).

- (2) Social media and citizen science websites. We searched for images of andromorph females in Libellulidae species on Google, Flickr, www.indianodonata.org, and Facebook groups such as “DragonflyIndia”. Keywords included names of three species of interest, *C. servilia*, *N. tullia*, *U. signata*, and other terms such as andromorph, androchrome, andromorph, and polymorphism.
- (3) Existing scientific literature. A literature search was done using keywords in Google Scholar, Dragonflies 0.9 database (managed by James Cook University), ResearchGate, and manuscripts in the collections of the authors.

A list of polymorphic Libellulids is given in Table 2; details of all records used in this study are given in the Appendix. Morphological terms follow Garrison, von Ellenrieder, & Louton (2006). Figure 8 was plotted using R statistical language (R Core Team 2017)

Description of species

1) *Crocothemis servilia* Figures 1, 2

Crocothemis servilia is one of Asia’s most widespread dragonfly species, ranging from the Arabian Peninsula in central Asia to Japan and Australasia in the far east. It has been introduced into Hawaii, the Caribbean Islands, Cuba and parts of the USA largely through imported aquatic plants and it has successfully established populations even in degraded or man-made habitats (Paulson, 1978a, 1978b).

Mature males of *C. servilia* are scarlet-red, whereas immature males are paler amber or orange colored; females are mostly yellow. An andromorph female and an amber-colored female were reported by van der Poorten (2007), but this has not been described elsewhere in literature as far as we are aware. Yokota and Asahina (1953) reported a gynandromorph female of this species, while andromorph females have been also reported from its sister species *Crocothemis erythrea* (Kotarac, 1996, 1999).

This species had the highest number of observed andromorph females ($n = 51$, see Table 2). There was variation in the coloration of these females and many andromorph females resembled the coloration of the paler red immature male ($n = 30/51$), while others resembled adult males with darker scarlet coloration ($n = 21/51$). Whether this variation in color is ontogenic or genetic needs to be further investigated. One female with coloration similar to an immature male caught by SJ was dissected, confirming the presences of eggs and thus a reproductively mature female (see Figure 2).

Andromorph females can be broadly categorized into two types: amber-colored females (resembling immature male) and scarlet females. The collected specimen was an amber type.

Brief description of the scarlet andromorph female (Figure 1a–c)

Head. Face scarlet or pink, only edges pale yellow, vertex scarlet; eyes apical 1/3rd maroon, rest dark green (completely red in some individuals); occipital triangle and posterior head orange.



Figure 1. *Crocothemis servilia* andromorph females with location, date and observer: (a) Hammaliya Estate, Sri Lanka; 20 October 2006; Nancy van der Poorten; (b) Aarey Colony, Mumbai, India; 3 September 2018; Photo: Rajesh Sanap; (c) Mannavannur, India; 29 October 2014; Bo Nielsen; (d) Aarey Colony, India; 1 December 2019; Dattaprasad Sawant; (e) male: Ambekhol Dam, Maharashtra, India; 26 October 2017; Dattaprasad Sawant; (f) heteromorph female: Devgad, Maharashtra, India; 12 September 2013; Dattaprasad Sawant.

Prothorax and *synthorax*. Uniformly vibrant scarlet; legs reddish-brown.

Wings. Basal patch dark reddish-brown; costal vein variously colored pale pink, brownish, or orange; basal venation pale red approximately to the level of the arcus, pterostigma variously colored brown, maroon, orange, yellow or red framed with black nervures, apices enfumed in some individuals.

Abdomen. Scarlet red but with patches of yellow or purple in some individuals; black mid-dorsal band extending from S2 to S10, darker posteriorly and more conspicuous than in the

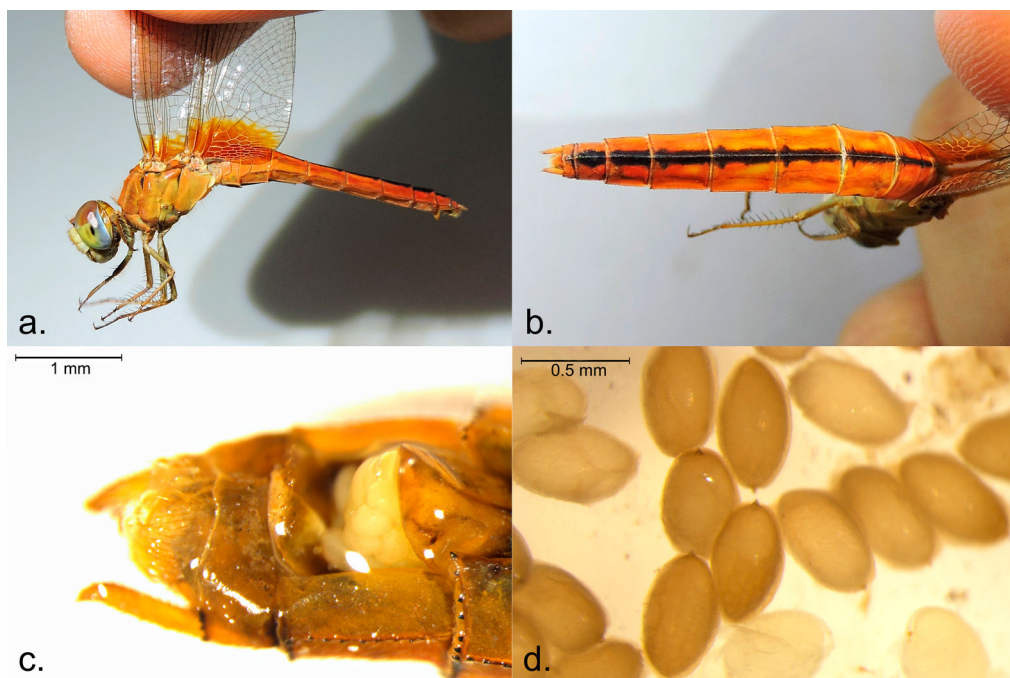


Figure 2. *Crocothemis servilia* andromorph female (NCBS- AV624): Diphupar “B”, Dimpaur District, Nagaland, India; 9 October 2016; leg. Shantanu Joshi. Deposited at Research Collections, National Centre for Biological Sciences, Bangalore. (a) left lateral habitus; (b) dorsal habitus; (c) ovipositor; and (d) eggs. Photos: (a, b) Joyce Veino, (c, d) Shantanu Joshi/National Centre for Biological Sciences, Bangalore.

amber-colored andromorph females; ovipositor scarlet; anal appendages pale pink or red, apices black.

Brief description of the amber or orange colored andromorph female (Figure 1d–f)

Head. Face off-white marked with scarlet or orange, vertex scarlet or orange; eyes apical 1/3rd reddish brown, rest olive green; occipital triangle and posterior head pale orange.

Prothorax and synthorax. Amber-colored sometimes with traces of scarlet; irregularly marked in some (Figure 1e); bright yellow antehumeral line on the mesepisternum faint, but visible; legs pale brown.

Wings. Pale brown basal patches on all wings, costal-vein golden yellow or pale yellow, basal veins yellow to the level of the arculus, pterostigma yellow to brown, apices enfumed.

Abdomen. Amber-colored; a black mid-dorsal band extending from S2 to S10, darker posteriorly; ovipositor pale orange; cerci orange in color, similar to S10.

Mature males (Figure 1e) differ from andromorph females in having: (a) eyes and face completely red, (b) legs red, and (c) anal appendages completely red.

Heteromorph females (Figure 1f) differ from andromorph females in having: (a) face, head, thorax and abdomen bright yellow to dull yellow, (b) legs pale brown or bright yellow, (c) basal patch of the wings yellow-brown, (d) costal vein bright yellow and (e) anal appendages pale brown.

2) *Diplacodes trivialis* Figure 3

Diplacodes trivialis is a widespread species ranging from India and further east through southeast Asia, through Indonesia to northern parts of Australia. It even inhabits distant islands in e.g. Japan, and reaches as far as Fiji in the Pacific.

The females (Figure 3d) and immature males of this species are yellow and black, with a white frons. The eyes are brown above, with the ventral half yellow. The eyes of the mature female are generally greenish above, and slightly bluish below. Mature males (Figure 3c) are covered with blue pruinescence that sometimes covers basal parts of the hind wings. The eyes are blue and the frons bright blue. The amount of pruinescence on the males varies greatly, and increases with age.

Andromorph females were photographed by E. Nielsen in Queensland, Australia, at two different locations: (1) 25 April 2017, Cumberland Dam, GPS coordinates: 18.30154 S, 143.35121 E; and (2) 12 May 2017, Cattana Wetlands; GPS coordinates: 16.83034 S, 145.70123 E. These females had the thorax and abdomen partially covered in blue pruinescence, and with a clear blue lower part on the eyes (Figure 3a, b).



Figure 3. *Diplacodes trivialis*: andromorph females (photos: Erland Nielsen) from Queensland, Australia: (a) 12 May 2017; (b) 25 April 2017; (c) male: Devgad, Maharashtra, India; 30 April 2014; Dattaprasad Sawant; and (d) heteromorph female: Devgad, Maharashtra, India; 30 April 2014; Dattaprasad Sawant.

3) *Neurothemis tullia* Figure 4

This is a widely distributed species common across the Indian subcontinent and occurring eastwards to China and Taiwan (Dow, 2009). Historically, this species contained two subspecies, *Neurothemis tullia tullia* (Drury, 1773) and *N. tullia feralis* (Burmeister, 1839), but the latter was



Figure 4. *Neurothemis tullia* andromorph females with location, date and observer: (a) Belvai, India; 19 October 2017; Sagar Sarang; (b) Sultanpur National Park, Haryana, India; 11 November 2018; Indushekhar Sharma; (c) male: Devgad, Maharashtra, India; 20 November 2019; Dattaprasad Sawant; and (d) heteromorph female: Belvai, India; 19 October 2017; Sagar Sarang.

recently elevated to the status of a separate species by Seehausen (2017). In this manuscript, we refer to *Neurothemis tullia*, *sensu* Seehausen (2017).

Asahina (1981) wrote about the variation in wing markings of this species, and figure 12 (in Asahina 1981) illustrates a female with wing markings like that of a typical adult male with the caption “Assam, androform, female, 13.X.1961”. Unfortunately, Asahina gives no further details on the occurrence of such females in this species. Seehausen (2017) also reported andromorph females in *Neurothemis tullia* and wrote, “Andromorph (or androchromotype) females have a dark basal wing coloration extending to the nodus in the Fw and up to three cells distal of the nodus in the Hw, with or without a white pruinescent band [. . .] I have examined andromorph females from India, Nepal and Laos.” This study provided an image of the wing of an andromorph female (figure 6f in Asahina 1981) but did not provide the location or any further description.

Lahiri (1979) published the first detailed account of an andromorph female of *Neurothemis tullia*. Six more females have been reported since then from India (Andrew, 2013; Emiliyamma, 2009; Kumar, 1988; Mitra, 1991; Prasad, Kulkarni, & Talmale, 2000; Prasad, Ramakrishna, Srinivasulu, & Srinivasulu, 2013). Emiliyamma (2009) reported a “gynandromorphic” female, but from the description it is clear that it is an andromorph female. Andrew (2013) observed an andromorph female ovipositing and dissected the female and provided images of eggs. We report

five additional records from India in this study based on photographs, four from the Odonata of India website and one from iNaturalist (see Table 2). Four out of the five females reported had coloration similar to an immature male (see the description below), while one andromorphic female resembled an old male with pruinescence.

Description of andromorph female based on published records and Figure 4

Head. Face brown, eyes dark brown or black in older individuals.

Prothorax, thorax and abdomen. Black. In most individuals the markings resemble immature males with a bright yellow stripe that starts anteriorly as small spots on median lobes of prothorax, extending posteriorly till S8, occupying approximately $\frac{3}{4}$ of S8 dorsally. These individuals are also marked laterally with yellow on S1–S7.

Wings. Proximal half black reaching one cell beyond nodus on costal side curved posteriorly, slight space (about half a cell) between the black marking and posterior margin of wings. Black marking followed by opalescent white bands medially approximately 3–4 cells, venation conspicuously white till about the level of pterostigma or 1–2 cells anterior to it; pterostigma dark brown or black.

Abdomen. Black, S1–S7 marked with yellow markings dorsally and laterally, marking not reaching posterior border on S7, S8–S10 black, Cerci white.

Immature males look very similar to females but differ from andromorph females in terms of darker thoracic coloration. Adult males (Figure 4c) differ from andromorph females in terms of having less extensive yellow markings on thorax and more extensive white bands on wings.

Heteromorph females (Figure 4d) differ from andromorph females in having: (a) coloration of wings (black band at the node and apices black in heteromorph; large rounded black marking till node, marked white after that); (b) yellow markings on abdomen: extent of yellow more in heteromorph females, S8 with dorsal yellow markings, S9 with two small yellow spots, S10 yellow, and S8–S10 black in andromorph females.

4) *Orthetrum pruinosum* Figure 5

Orthetrum pruinosum is widely distributed from India, Sri Lanka, east to Japan, the Philippines and south to Malaysia, Taiwan and the Sunda Islands.

A single andromorph female was photographed by Chirag Parmar on 15 November 2015 at Ratanmahal Sloth Bear Sanctuary, Anand, Gujarat, India. This female differs from the usual females in terms of its abdominal and basal wing coloration (Figure 5).

Brief description of andromorph female

Head. Eyes blue above, brownish below.

Prothorax and thorax. Prothorax and thorax brown, metascutum brighter brown.

Wings. Wings hyaline, with reddish-brown basal marking; basal marking inconspicuous on forewings restricted to the basal membrane, more extensive on hind wing reaching midway between 1st and 2nd antenodal nervures and occupying approximately half of median space; costal vein yellow.

Abdomen. Scarlet-pink, S9–10 and anal appendages brown.

This observed andromorph females differs from the adult male (Figure 5b) by: (a) color of synthorax (pruinose in male); and (b) brown basal wing patch less pronounced.

Heteromorph females (Figure 5c) differ from this andromorph female by having: (a) brown basal wing patch fainter; (b) costal vein black; and (c) abdominal color brown.



Figure 5. *Orthetrum pruinolum*: (a) andromorph female: Ratanmahal Sloth Bear Sanctuary, India; 15 November 2015; Chirag Parmar; (b) male: Kondeshwar, Maharashtra, India; 23 February 2020; Dattaprasad Sawant; and (c) heteromorph female: Devgad, Maharashtra, India; 15 August 2016.

5) *Urothemis signata* Figure 6

Urothemis signata is widely distributed from India, Sri Lanka, Indo-China, to Sundaland, Taiwan, Australia and New Guinea.

It was first described as *Libellula sanguinea* from a male and female from Madras, India but no type was designated; the abdomen was described as red (“*corpore sanguineo*”). Most authors consider that the typical female has a greenish-yellow or brown abdomen and thorax, with black markings (e.g. De Fonseka, 2000; Subramanian, 2005), but the original description mentions that the abdomen is reddish. Rambur (1842) described only the female (which is now the holotype), writing that the abdomen was reddish-yellow with dorsal black spots. Sélys (1897) described the male as having a reddish abdomen “during life” and the female as being similar to the male except that the abdomen was reddish-brown and the sutures black. Ris (1913) described the male as having a red abdomen with a narrow black dorsal stripe along segments 8 and 9; the female is described as having the abdomen yellowish to reddish brown from segment 3 onwards with a black dorsal band, which widens at the end of the segment almost to the lateral edge. He also described a female specimen from Hanoi that had a dull red-brown abdomen. Fraser (1936) wrote that the female abdomen is “greenish-olivaceous, sometimes reddened on the dorsum as in the male”. Bedjanič et al. (2014) mentioned that, “Androchrome females have also been recorded”, but gave no further details.

Brief description of the andromorph female (Figure 6)

Head. Eyes and face as per the typical female.

Prothorax and synthorax. Dull yellow or amber with no black lateral stripes in some individuals; in others thorax is same as in heteromorph female or with reduced black stripes (Figure 6e); legs dark brown to black.

Wings. Hind wing with black basal patch edged with yellow or reddish-orange; costal vein variously colored red, yellow, or orange; basal venation red, yellow or orange approximately to the level of the arculus, pterostigma variously colored brownish or reddish, framed with black nervures.

Abdomen. Dorsum red, reddish or orange, patchy in some individuals, S8–10 dorsum black; S3–7 with apical black dorsal markings; ovipositor yellow or reddish-yellow. Cerci reddish, apices black.

Heteromorph females (Figure 6f) differ from andromorph females in having (a) thorax bright yellow with 3 black lateral stripes; (b) abdomen bright yellow, S8–10 almost entirely black, S3–7 with black dorsum and black apical and basal laterally; (c) basal nervures black; (d) ovipositor yellow with black base; and (e) anal appendages yellow tipped black.

Mature males (Figure 6e) differ from andromorph females in having (a) face and eyes completely red; (b) thorax red; (c) nervures at base of wings red; (d) abdomen red with dorsum black on S8–10 and small black dorsal marks on S3–7; and (e) anal appendages red.

Teneral males differ from andromorph females in having (a) thorax yellow; (b) nervures at base of wings yellow; (c) abdomen yellow with black dorsal markings as in mature male; and (d) anal appendages yellow.

6) *Bilateral gynandromorph male of Brachythemis contaminata*

Jenis Patel photographed a bilateral gynandromorph male (as evidenced by the male anal appendages and secondary genitalia) of *B. contaminata* at Ahwa Lake, Ahwa, Dang District, Gujarat, India on 3 September 2015. The bilateral gynandromorph male was seen at an urban

lake with high anthropocentric pressure and vegetation around the edges and is the first record of gynandromorphism in this species. Photos of male and female are given in Figure 7b, c for reference.

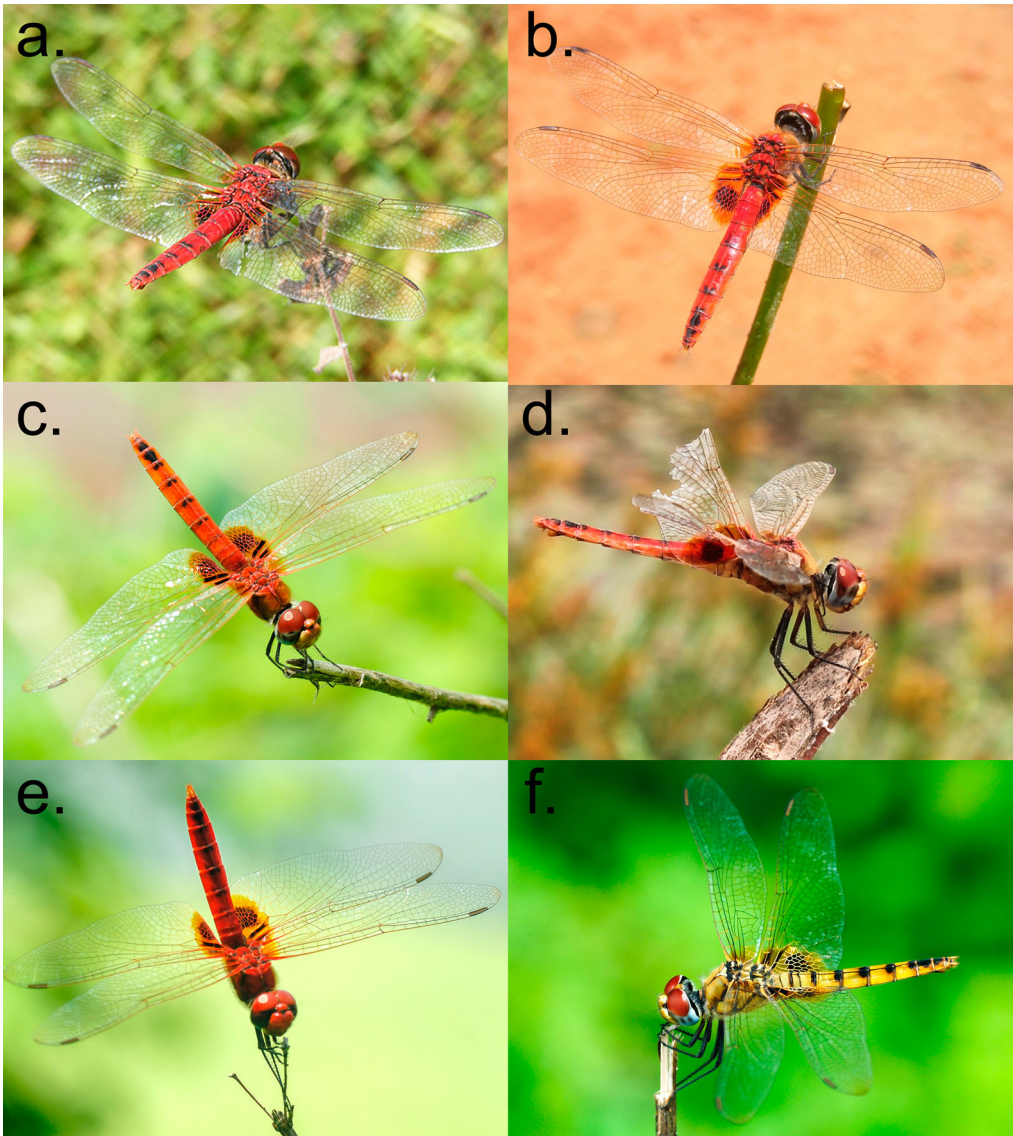


Figure 6. *Urothemis signata* andromorph female with location, date and observer: (a) Chalavara, India; 6 November 2015; Muhamed Sherif; (b) Chalavara, India; 24 September 2016; Muhamed Sherif; (c) Chongaon Lake, India; 29 July 2019; Dattaprasad Sawant; (d) Thalawathugoda, Sri Lanka; 20 June 2014; Amila Sumanapala; (e) male and (f) heteromorph female: Chon Lake, Maharashtra, India; 14 July 2019.

Description of the observed male based on Figure 7a

Head. Face brown, eyes dark brown above, ventral half green.

Prothorax and synthorax. Starting from the synthorax the right half of the individual is marked like a female while the left half is marked like the male. The difference is especially apparent on the synthorax and wings. Synthorax right half pale greenish brown, left half more orange colored, metepimeron of right half orange like the left half.

Wings. Right pair of wings hyaline, veins towards costal margin orange, pterostigma yellow; left pair of wings marked orangish-brown till the level of pterostigma at the costal side, the marking curved anteriorly towards anal margin, pterostigma dark orange, venation orange.

Abdomen. Orange with black mid-dorsal carina, right half of the abdomen marked laterally yellow on S3–5. Anal appendages orange.

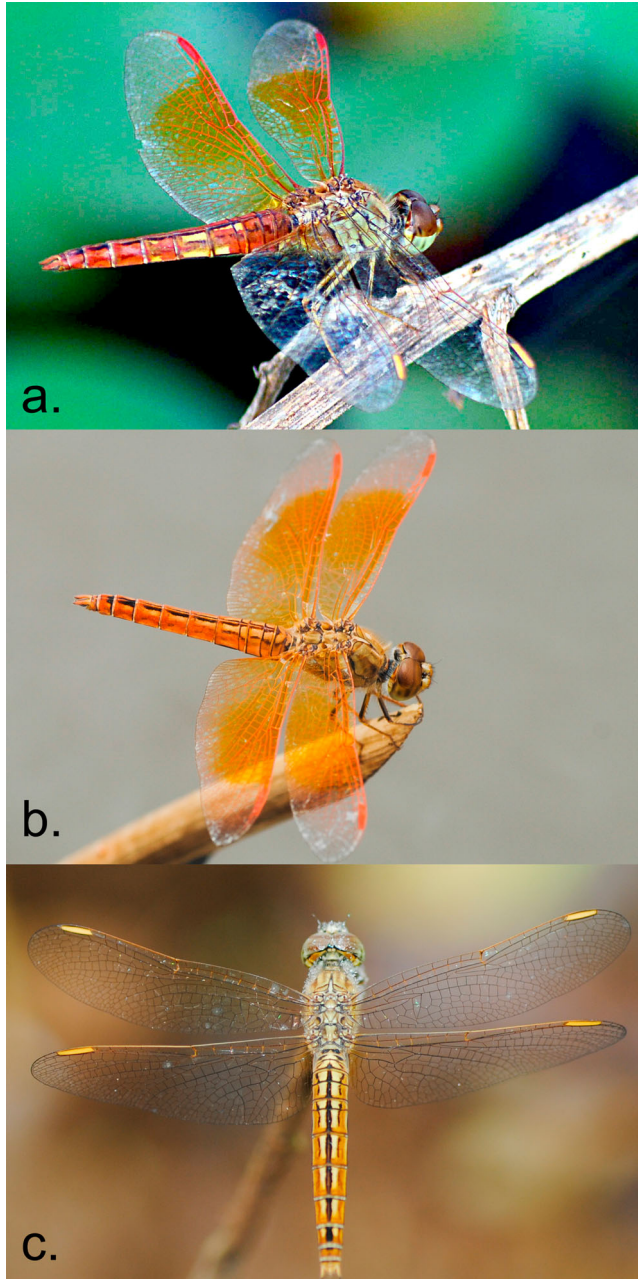


Figure 7. *Brachythemis contaminata*: (a) bilateral gynandromorph male: Ahwa, Gujarat, India; 3.IX.2015; Jenis Patel; (b) male: Gadheshwar, Maharashtra, India; 5 August 2018; Dattaprasad Sawant; and (c) female: Aarey Colony, Maharashtra, India; 2 September 2018; Dattaprasad Sawant.

Table 1. Sources of data used to compile records of andromorph *Crocothemis servilia*, *Neurothemis tullia* and *Urothemis signata* females in Table 2.

No.	Source	Source category	No. of records (worldwide)	No. of records (India)
1	Dragonflies and Damselflies_Worldwide Odonata	Facebook group	2	1
2	Dragonflies of Kerala	Facebook group	6	6
3	Dragonflies of Kerala/DragonflySouthAsia	Facebook group	1	1
4	DragonflySouthAsia	Facebook group	14	14
5	DragonflySouthAsia/ iNaturalist	Facebook group/dedicated website	2	2
6	Flickr	Flickr	4	2
7	iNaturalist	Dedicated website	21	5
8	Odonata of India	Dedicated website	10	10
9	Allodonata	Dedicated website	1	1
10	Odonata of India/DragonflySouthAsia	Dedicated web-site/Facebook group	1	1
11	Published record	Published record	9	8
12	Unpublished observation	Unpublished observation	18	9
		Total	89	60

1 <https://www.facebook.com/groups/odonata/>

2 <https://www.facebook.com/groups/1401144716840784/>

4 <https://www.facebook.com/groups/dragonflyindia/>

6 <https://www.flickr.com/>

7 <https://www.indianodonata.org/>

8 <http://allodonata.com/> [Defunct since April 2019]

Discussion

Various questions about the role of coloration and polymorphism in Libellulid dragonflies are being investigated (e.g. Futahashi, 2017; Futahashi, Kurita, Mano, & Fukatsu, 2012), but the extent and occurrence of polymorphism in this family is not well understood. This may be due to the genuine rarity of polymorphic dragonflies or because of under-reporting of such observations. While a lot of research has focused on polymorphism in the Zygoptera, much less attention has been paid to the occurrence of the same phenomenon in the Anisoptera. Polymorphism has seldom been reported in detail for Libellulidae species, possibly due to the compounding issue of age-related color variation and difficulties in publishing isolated records.

We demonstrate that at least in the case of our three focal species, *Crocothemis servilia*, *Neurothemis tullia*, and *Urothemis signata*, the occurrence of andromorph females has been underreported as shown by the high number of records in this study.

Eighty-nine records were compiled from various sources (see Table 2 and Appendix) collected by 59 observers for these three species. The highest number of observations of andromorph females was for the species *Crocothemis servilia* ($n = 51$). The highest numbers of records were from the years 2018 and 2019, when combined data for all three species was plotted (Figure 8). This probably reflects a higher number of observers and improved methods of sharing records rather than being reflective of an actual increase in number of andromorph individuals. Records were obtained from in total nine countries, while the majority ($n = 60/89$, 68%) of records were from India. More focused research on andromorph and heteromorph females in Libellulid species is required to understand the relative frequencies and seasonality of these morphs. This is an ecologically relevant trait, as recent studies shows that more widespread and abundant odonate species are more likely to exhibit polymorphism than rare or threatened species (Takahashi & Noriyuki, 2019).

Citizen science has gained tremendous popularity as a tool in biodiversity research in recent years. Community based monitoring of environmental biological variables is already adding

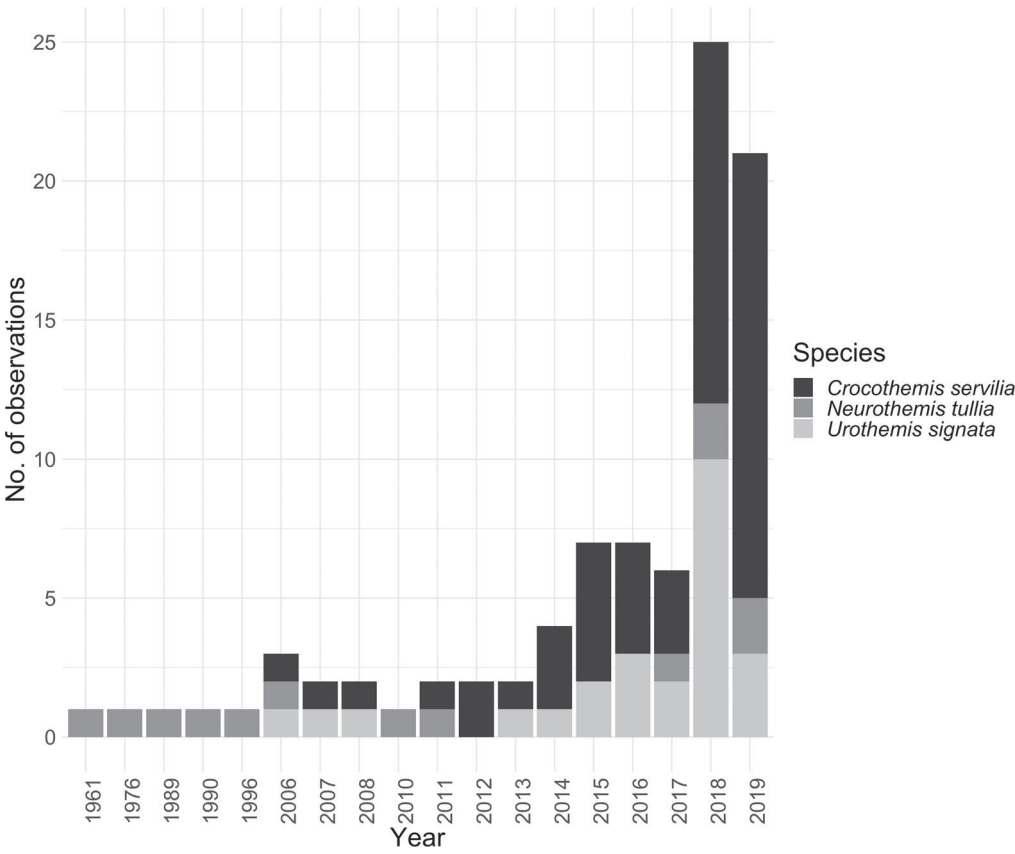


Figure 8. Number of records of andromorph females of *C. servilia*, *N. tullia*, and *U. signata* per year from 1961 to 2019 (years with 0 observations are not depicted).

Table 2. List of polymorphic species in the family Libellulidae from Asia (except *Diplacodes trivialis*, which is reported from Australia).

Species	Total number of records	Reference
<i>Brachythemis contaminata</i> *	1	This study
<i>Camacinia gigantea</i>	2	Ang (2016)
<i>Crocothemis servilia</i> *	51	This study; van der Poorten 2007
<i>Diplacodes trivialis</i> *	1	This study
<i>Neurothemis fluctuans</i>	1	Fraser (1936)
<i>Neurothemis fulvia</i>	1	Fraser (1936)
<i>Neurothemis intermedia</i>	1	Prasad et al. (2000)
<i>Neurothemis tullia</i> *	13	See Table 2
<i>Orthetrum pruinsum</i> *	1	This study
<i>Urothemis signata</i> *	25	This study

* New records published in this study

significant knowledge about biodiversity, e.g. 27% of all insect records on the Global Biological information facility are contributed by citizen scientists (Chandler et al., 2017). As the use of social media and the uploading of images increases rapidly, photograph-based records are being used widely in fields such as taxonomy (Gonella, Rivadavia, & Fleischmann, 2015; Skejo, Caballero, & Honezza, 2016). Such records can be useful in studying variation in morphological

traits as well, as we demonstrate. Our study also forms an example of how primary biodiversity data (Barve, 2014) from various online sources can be used in meaningful ways in conjunction with published and unpublished records. Odonates are ideal for using photo-based observations to discover new species and new distribution records among other things (e.g. Abbott & Hibbitts, 2011; Cordero-Rivera, Romeo Barreiro, & Cabana-Otero, 2019), as they are widespread, easy to observe, relatively well studied, and morphologically identifiable in most cases. Through projects like the recent Odonate phenotypic database (Waller, Willink, Tschol, & Svensson, 2019), this problem is being addressed and our study exhibits how citizen science data in conjunction with other records can be used to understand phenotypic variation in dragonflies.

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Appendix

List of all records obtained for three focal species: 1. *Crocothemis servilia*, 2. *Neurothemis tullia*, and 3. *Urothemis signata*, including date, locality, observer and source

Species	Date (dd/mm/yy)	Locality	Observer	Source (see Table 2)
1	01/08/16	Cuttack, Odisha, India	Ashesh Rathor	DragonflySouthAsia
1	15/10/14	Mannavanur, Kodaikanal, Tamil Nadu, India	Bo Nielsen	DragonflySouthAsia
1	29/10/14	Mannavanur, Kodaikanal, Tamil Nadu, India	Bo Nielsen	DragonflySouthAsia
1	16/10/12	Mulund, Mumbai, Maharashtra, India	Ajay Ramkishnan	DragonflySouthAsia
1	07/07/17	Chikhli, Gujarat, India	Piyush Patel	DragonflySouthAsia
1	08/10/15	Tadoba TR, Maharashtra, India	Pranad Patil	Odonata of India
1	01/10/15	North West Bengal, India	Achintya Adhikari	DragonflySouthAsia
1	13/08/15	Nagercoil, Tamil Nadu, India	Bala Chandran	DragonflySouthAsia
1	01/07/16	Durgapur, Bardhaman District, West Bengal, India	Rajib Maulick	DragonflySouthAsia/iNaturalist
1	03/07/15	Devgad, Sindhudurg District, Maharashtra, India	Dattaprasad Sawant	Odonata of India
1	09/10/16	Veino Residence, Diphupar “B”, Dimapur District, Nagaland, India	Shantanu Joshi	Unpublished observation
1	19/08/11	Pune, Maharashtra, India	Rahul Singh Lamba	Flickr
1	11/11/08	Mohurli Lake, Tadoba National Park, Maharashtra, India	Andre Gunther	allodonata
1	24/04/18	Jim Corbett National Park, Ramnagar District, Uttarakhand, India	Vansh Muthana	DragonflySouthAsia
1	03/09/18	Aarey Milk Colony, Mumbai District, Maharashtra, India	Rajesh Sanap	Odonata of India

(Continued)

Species	Date (dd/mm/yy)	Locality	Observer	Source (see Table 2)
1	06/10/18	Futala Lake, Nagpur, Nagpur District, Maharashtra, India	Shantanu Joshi	Unpublished observation
1	06/10/18	Futala Lake, Nagpur, Nagpur District, Maharashtra, India	Shantanu Joshi	Unpublished observation
1	29/02/16	Olatthoduvai, Mannar Island, Sri Lanka	Amila Sumanapala	Unpublished observation
1	01/05/17	Ayli tank, Puttalam district, Sri Lanka	Amila Sumanapala	Unpublished observation
1	30/09/14	Kalamatiya, Hambantota district, Sri Lanka	Athula Edirisinghe	Unpublished observation
1	12/01/19	Chena Wetlands, Versova, Thane District, Maharashtra, India	Dattaprasad Sawant	Odonata of India
1	25/05/19	Palakkad, Kerala, India	Balachandran Puliampotta	DragonflySouthAsia
1	25/05/19	Kadma, Bankura District, Paschimbanga, India	Aniruddha Singhamahapatra	Odonata of India
1	02/06/19	DVC Canal, Baidyabati, Hoogly district, Paschimbanga, India	Kausik Ghosh	Odonata of India
1	13/08/13	Mulund, Mumbai, Maharashtra, India	Ajay Ramrkishnan	iNaturalist
1	16/09/15	Godhra, Godhra District, Gujarat, India	Username: chiefreearth	iNaturalist
1	20/10/06	Hammaliya Estate, North Western Province, Sri Lanka	Nancy van der Poorten (in van der Poorten 2007)	Published Observation
1	02/05/07	Hammaliya Estate, North Western Province, Sri Lanka	Nancy van der Poorten	Unpublished observation
1	29/09/18	Lucknow, Lucknow District, Uttar Pradesh, India	Poonam Nayaka	DragonflySouthAsia
1	21/09/18	Punjab, India	Tanya Vinit Mishra	Dragonflies and Damselflies_Worldwide Odonata
1	23/06/19	Mahim Wetland, Palghar District, Maharashtra, India	Dattaprasad Sawant	Unpublished observation
1	23/06/19	Mahim Wetland, Palghar District, Maharashtra, India	Dattaprasad Sawant	Unpublished observation
1	23/06/19	Mahim Wetland, Palghar District, Maharashtra, India	Dattaprasad Sawant	Unpublished observation
1	14/07/19	Puzhakkal, Punnamm, Thrissur District, Kerala, India	Manoj Karingamadathli	iNaturalist
1	18/02/19	Sumbawa, Nusa Tenggara Barat, Indonesia	Deny Wahyudi	iNaturalist
1	22/07/19	Durgapur, Bardhaman District, West Bengal, India	Rajib Maulick	Odonata of India/Dragonfly SouthAsia
1	10/02/19	Sumbawa, Nusa Tenggara Barat, Indonesia	Deny Wahyudi	iNaturalist
1	06/03/18	Lape, Kabupaten Sumbawa, Nusa Tenggara Barat, Indonesia	Deny Wahyudi	iNaturalist
1	10/02/18	Jorok, Unter Iwes, Sumbawa Regency, West Nusa Tenggara, Indonesia	Deny Wahyudi	iNaturalist
1	04/08/17	Qiubei, Wenshan, Yunnan, China	Mike	iNaturalist
1	26/08/18	Tanglin, Singapore	Marcel Finlay	iNaturalist
1	09/10/18	Oecussi-Ambeno, Timor-Leste	Rui Da Silva Pinto	iNaturalist
1	22/11/18	Rua da Minha, Ai-Tarak-Laran, Dili, Timor-Leste	Jafet Potenzo	iNaturalist

(Continued)

Species	Date (dd/mm/yy)	Locality	Observer	Source (see Table 2)
1	28/04/19	Aosnak, Oecussi-Ambeno, Timor-Leste	Rui Da Silva Pinto	iNaturalist
1	10/05/12	Devsar, Gujarat, India	Jenis Patel	iNaturalist
1	18/08/19	Thumboor, Thrissur, Kerala, India	Vivek Chandran	Dragonflies of Kerala
1	15/10/19	Thumboor, Thrissur, Kerala, India	Rison Thumboor	Dragonflies of Kerala
1	21/10/18	Kole Wetlands, Thrissur, Kerala, India	Muhamed Sherif	Dragonflies of Kerala/Dragonfly SouthAsia
1	09/10/18	Changanassery, Kottayam, Kerala, India	Abraham Samuel	Dragonflies of Kerala
1	01/12/19	Lotus Lake, Aarey Colony, Mumbai Suburban District, Maharashtra, India	Dattaprasad Sawant	Unpublished observation
1	30/11/19	Kranti Nagar, Bhandup, Mumbai Suburban District, Maharashtra, India	Dattaprasad Sawant	Unpublished observation
2	01/03/06	Kasargod District, Kerala, India	K. G. Emiliyamma (in Emiliyamma 2009)	Published record
2	23/03/11	Manjeera Wildlife Sanctuary, Medak District, Andhra Pradesh, India	Prasad et al. 2013	Published record
2	02/11/10	Telenkhedi Pond, Nagpur City, Nagpur District, Maharashtra, India	R. A. Andrew (in Andrew 2013)	Published record
2	12/10/96	Totladoh, Pench Tiger Reserve, Seoni District, Maharashtra, India	Anil Mahabal (in Prasad et al. 2000)	Published record
2	13/10/61	8 mile east of Ledo, Tinsukia District, Assam, India	S. Asahina (in Asahina 1981)	Published record
2	03/09/89	Sahaspur, Dehra Dun, Uttarakhand, India	Arun Kumar (in Kumar 1988)	Published record
2	15/06/76	Dihing Wildlife Sanctuary, Tinsukia District, Assam, India	S. Chandra (in Lahiri 1979)	Published record
2	07/05/90	Faizabad, Faizabad District, Uttar Pradesh, India	Tridib Mitra (in Mitra 1991)	Published record
2	19/10/17	Belvai, Dakshina Kannada District, Karnataka, India	Sagar Sarang	Odonata of India
2	24/11/18	Kalinga Mane, Agumbe, Shivamogga District, Karnataka, India	Abhijeet Bayani	Odonata of India
2	11/10/18	Sultanpur National Park, Gurugram District, Haryana, India	Indushekhar Sharma	iNaturalist
2	02/11/19	Umred Karhandla, Nagpur District, Maharashtra, India	Shailesh Gupta	Odonata of India
2	24/11/19	Idamaruku, Idukki District, Kerala, India	Arun Lal	Odonata of India
3	06/11/15	Chalavara, Palakkad, Palakkad District, Kerala, India	Muhamed Sherif	DragonflySouthAsia
3	09/10/16	Chalavara, Palakkad, Palakkad District, Kerala, India	Muhamed Sherif	DragonflySouthAsia
3	24/09/16	Chalavara, Palakkad, Palakkad District, Kerala, India	Muhamed Sherif	DragonflySouthAsia
3	24/09/18	Chalavara, Palakkad, Palakkad District, Kerala, India	Muhamed Sherif	DragonflySouthAsia
3	04/05/17	Ugat, Dahin Nagar, Surat City, Surat District, Gujarat, India	Mohit Patel	DragonflySouthAsia/ iNaturalist

(Continued)

Species	Date (dd/mm/yy)	Locality	Observer	Source (see Table 2)
3	20/06/14	Thalawathugoda, Colombo district, Sri Lanka	Amila Sumanapala	Unpublished observation
3	14/11/16	Thalangama, Colombo district, Sri Lanka	Bandu Biyanwila	Unpublished observation
3	31/08/13	Semantan, Pahang, Malaysia	Erland Refling Nielsen	Flickr
3	27/10/18	Ezhupunna, Alappuzha district, Kerala, India	Renju In	Dragonflies of Kerala
3	09/04/17	Kottanellur, Kerala, India	Rison Thumboor	Flickr
3	18/12/08	Khong Chiam, Thailand	Collin Adams	Dragonflies and Damselflies - Worldwide Odonata
3	24/01/06	Hammaliya Estate, North Western Province, Sri Lanka	Nancy van der Poorten	Unpublished observation
3	27/01/07	Hammaliya Estate, North Western Province, Sri Lanka	Nancy van der Poorten	Unpublished observation
3	01/05/15	Hammaliya Estate, North Western Province, Sri Lanka	Nancy van der Poorten	Unpublished observation
3	19/07/19	Chongaon Lake, Ambarnath Taluka, Thane District, Maharashtra, India	Dattaprasad Sawant	Unpublished observation
3	11/11/18	Kranji Marshes, Singapore	Maludin Mohammed	iNaturalist
3	11/11/18	Neo Tiew Lane 2, Singapore	yueting	iNaturalist
3	10/03/18	Sungei Buloh Wetland Reserve, Singapore	Marcus Ng	Flickr
3	11/03/18	Yishun, Singapore	Marcus Ng	iNaturalist
3	14/09/18	Haitang, Sanya, Hainan, China	iNaturalistUser_TheLittleMan	iNaturalist
3	12/01/19	Neo Tiew Rd, Singapore	Marcus Ng	iNaturalist
3	16/06/19	Neo Tiew Rd, Singapore	Marcus Ng	iNaturalist
3	18/12/18	Pursat, Pouthisat, Bakan, Cambodia	Sarom	iNaturalist
3	01/08/18	Keeriyad, Kannur, Kerala, India	Afsar Nayakkan	Dragonflies of Kerala
3	28/07/18	Panachikkadu, Kottayam, Kerala, India	Renjith Jacob Matthews	Dragonflies of Kerala

Bilateral gynandromorph male (rest are andromorph females)